TITLE:

Revisiting the phonological deficit in dyslexia: are implicit non-orthographic representations impaired?

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Catherine Dickie, Mitsuhiko Ota

Linguistics and English Language, University of Edinburgh

Ann Clark

Speech and Hearing Sciences, Queen Margaret University, Edinburgh

First author full affiliation:

Catherine Dickie,

University of Edinburgh

Linguistics & English Language

Dugald Stewart Building

3 Charles Street

Edinburgh

EH8 9AD

Tel 0131 651 3952

Email cath.ling1@gmail.com

Fax 0131 651 3190

Abstract

This study investigates whether developmental dyslexia involves an impairment in implicit phonological representations, as distinct from orthographic representations and metaphonological skills. A group of adults with dyslexia was matched with a group with no history of speech/language/literacy impairment. Tasks varied in the demands made on (implicit) phonological representations versus metalinguistic analysis/manipulation, and controlled the contribution of phonological versus orthographic representations by including both a segmental and an equivalent suprasegmental (non-orthographic) version of each task. The findings show a dissociation between metaphonological skills and implicit phonological representations, with the dyslexic group impaired in metaphonological manipulation skills in both segmental and suprasegmental tasks, but not in implicit knowledge of phonological contrasts.

Revisiting the phonological deficit in dyslexia: are non-orthographic phonological representations impaired?

Developmental dyslexia is widely believed to be caused either mainly (Snowling, 2000; Ramus, 2003) or in part (Stein & Walsh, 1997; Wolf et al., 2002) by a phonological deficit. In contexts where individuals with dyslexia are required to demonstrate a mastery of phonological units such as phonemes and syllables, their performance is consistently found to be weaker than that of controls matched for chronological age and/or reading age. This includes performance on phoneme deletion (Fawcett & Nicolson, 1995; Wilson & Lesaux, 2001), phoneme counting (Bruck, 1992), and syllable counting or deletion tasks (Pratt & Brady, 1988). Other tasks with a phonological component, such as rapid naming and nonword repetition, also elicit weaker performance from dyslexic than non-dyslexic individuals (Denckla & Rudel, 1976; Brady, 1991).

A broad consensus has arisen in the field that this phonological deficit can be traced back to an impairment of phonological representations or phonological coding, defined as "the ability to use speech codes to represent information in the forms of words and word parts" (Vellutino, Fletcher, Snowling, & Scanlon, 2004: 12). Phonological representations have been implicated as causally linked to all the various manifestations of the phonological deficit, from paired associate learning and nonword repetition, to phonological awareness and reading (Brady, 1991; Ramus, 2003; Ramus, Pidgeon, & Frith, 2003; Snowling, 2000; Stanovich, 1988; Thomson, Richardson, & Goswami, 2005).

However, two issues relating to phonological representations in dyslexia require further attention. One is the relationship between phonemes (as phonological segments) and the segments of conventional orthography (letters or graphemes). The other is the relationship between phonological awareness and phonological representations. Let us now consider each of these issues in turn.

Phonological and orthographic segments

One controversial issue in dyslexia research is the nature of the relationship between phonological knowledge and familiarity with a writing system. Although spoken language and written language differ from each other in many significant ways, the two modalities nevertheless have a great deal in common. Current influential accounts of dyslexia seek to relate the deficit in written language to a deficit in aspects of spoken language (Snowling, 2000; Ramus, 2003), but the challenge which confronts this approach is the issue of how to handle what Harris (2000) calls the “symbiotic relationship” between these two modalities.

Learning to read and write in any orthographic system means that learners have to reshape their analyses of the sounds of words so as to match the analysis conveyed or implied in a word’s conventional spelling (Treiman, 1997), and familiarity with spelling conventions is known to affect people’s concept of the properties of spoken words (Ehri, 1992; Treiman & Danis, 1988; Treiman & Cassar, 1997; Shankweiler & Fowler, 2004; Ziegler & Ferrand 1998). It is increasingly being recognised, more specifically, that segmentation at the phoneme level is unlikely to arise spontaneously for most people, but only when alphabetic literacy provides an impetus to do so (and a convenient, culturally shared example of how to do it) (Derwing, 1992; Olson, 2002; Port, 2007; Silverman, 2006; Treiman, 1997).

If the phonemic segmentation of spoken words is supported by familiarity with alphabetic conventions, then there is a conceptual problem when we find that individuals with dyslexia are impaired in phonemic segmentation skills: such a finding may be nothing more than a circular restatement of what is already known of dyslexia; that is, that it involves difficulty with the conventions of written language.

This issue forms the background to the first main aim of this study: the need to test phonological knowledge which is independent of orthographic knowledge. For the purposes of the present study, it is assumed that any task which involves phonemic segments is liable to be approached with the individual's knowledge about the conventions of alphabetic orthography. We will therefore examine non-segmental aspects of English phonology which do not overlap with orthography.

Phonological representations and phonological awareness

The second controversial issue in dyslexia research is the extent to which tasks that tap into different kinds of metalinguistic skills can be informative about mental representations of spoken language. Although it has usually been assumed that a phonological awareness deficit constitutes evidence of a phonological representations deficit, this assumption is not necessarily warranted.

As noted above, the phonological deficit in dyslexia is most commonly identified in tasks which require participants to identify segments within words and perform some mental operation on these segments (such as deleting or substituting them). The most prominent feature of these tasks, however, is that they are metalinguistic in nature, rather than specifically targeting phonological representations.

There is of course a wide range of views on the nature of phonological representation. Here, we take what we believe is the most pre-theoretical approach to linguistic knowledge that is available, and suggest that phonological representations are what are assumed to underlie speakers' understanding about meaningful differences in the phonological patterns of linguistic structures. For instance, the contrast between /p/ and /b/ in English distinguishes the lexical items *pin* and *bin*, and the position of stress distinguishes the meaning of *Énglish teacher* from that of *English teácher*. Regardless of how precisely this knowledge is or is not mentally represented, it remains the case that although this type of knowledge is essential for successful communication, not all of it is necessarily available to analytical introspection by the speakers of a language.

Metalinguistic analysis, on the other hand, requires that rather than simply making use of such phonological information as a means to a communicative end, the speaker must instead be able to access it as an object of investigation in its own right. Metalinguistic analysis of some kind is widely agreed to be necessary in the process of learning to read (although opinions differ as to whether this metalinguistic analysis is a prerequisite to approaching written text (Tunmer & Bowey, 1984) or a consequence of engagement with it (Scholes & Willis, 1991)). Nevertheless, despite its importance for literacy, the knowledge gained through conscious, metalinguistic introspection is rather different in its nature from implicit phonological knowledge (Pierrehumbert et al., 2000). This can be expressed informally as the difference between 'just using' language and 'thinking about' language: metalinguistic analysis demands the adoption of a reflective viewpoint on language which is not necessary for efficient and fluent verbal communication (Tunmer & Herriman, 1984).

Although all parties agree that in the nature of things, it will always be difficult to test experimentally the nature of implicit linguistic representations, two sets of studies suggest that the issue of whether or not phonological representations are indeed impaired in dyslexia cannot yet be treated as resolved. On the one hand, results reported by Boada and Pennington (2006) suggest that implicit representations may be impaired in dyslexia. They report that children with dyslexia showed more syllable-level confusions than phoneme-level confusions in a syllable similarity task, indicating that their representations are not yet mature enough to be organised on the basis of phonemes rather than syllables; they also reported that children with dyslexia require more acoustic information than age-matched peers in order to identify the correct word in a lexical gating task; and thirdly in a priming study they showed that while priming benefited word identification in all their participants, the participants with dyslexia were unable to benefit as much as controls from short primes. These findings are presented as converging evidence in favour of a deficit in implicit representations in dyslexia. The same conclusion is drawn by Elbro, Borstrøm, and Petersen (1998) and Elbro and Pallesen (2002), who elicited 'clear' productions from children by asking them to correct the pronunciation of 'indistinct' pronunciations made by a toy parrot. On the basis that children at risk for dyslexia show 'less distinct' pronunciations than controls, these authors conclude that their implicit phonological representations are also indistinct. However, it is not clear how exactly to view the relationship between production data and implicit phonological representations: in this particular study, the 'corrected' pronunciation of a word may involve an over-articulated form that does not accurately reflect participants' typical productions, and more generally it has been argued that truncation errors similar to those shown in these children's productions are not in fact reflective of representational deficits but are rather due to a developing phonology which constrains the child's output in well-formed although non-adult-like ways (Demuth, 1996).

On the other hand, results from a series of studies reviewed by Ramus and Szenkovits (2008) point in a different direction. These studies investigated the probabilistic and typically language-specific processes which they call 'phonological grammar,' something which should be expected to be impaired if phonological representations are indeed impaired in dyslexia. However, dyslexic and non-dyslexic participants were equally sensitive to the legality of voicing assimilations, equally liable to experience perceptual illusions induced by language-specific phonotactic constraints, and equally susceptible to subliminal repetition priming.

Ramus and Szenkovits (2008) have therefore argued that, far from being degraded, in dyslexia, "phonological representations are intact, that grammatical processes that operate on them are intact too, and that the deficit lies somewhere else" (Ramus & Szenkovits 2008: 135). It is possible that some of the findings reported by Boada and Pennington (2006) can be accounted for by considering that the tasks assume the phoneme as a linguistic unit, a position which, as noted in the previous section, is unlikely to do justice to the phonological representations of individuals with dyslexia due to the alphabeticism confound. This problem is avoided by Ramus and Szenkovits (2008), who have looked at non-segmental (sub-phonemic) phenomena, where literacy skills are likely to play less of a role.

This issue therefore provides the motivation for the second main aim of this study: in addition to controlling for segmentality, we will also test phonological skills in individuals with dyslexia in a way which controls the degree of metalinguistic analysis required.

Aims

The two aims of this study can therefore be framed as the following research questions. (1) How do individuals with dyslexia perform on tasks which do and do not allow participants the option of drawing on orthographic knowledge in order to perform the putatively phonological aspects of the task? (2) How do individuals with dyslexia perform on tasks which vary in the implicit versus metalinguistic demands they make?

In order to address these aims, four tasks were devised, each with two different versions. Aim (1) was addressed by ensuring that each task consisted of both a segmental version (corresponding to areas of phonology which have orthographic counterparts) and a suprasegmental version (corresponding to areas of phonology which have no orthographic counterpart, and where recourse to orthographic knowledge was excluded). Aim (2) was addressed by using tasks which separately tested aspects of phonological competence with increasing degrees of metalinguistic analysis: (a) the ability to identify the referents of words that differ by phonological contrasts (the ‘Picture Matching’ task), (b) the ability to identify units of phonological representation in linguistic structures (the ‘Unit Monitoring’ task), (c) the ability to manipulate a phonological unit within a word (the ‘Pig Latin’ task), and (d) the ability to manipulate two phonological units with additional working memory demands (the ‘Spoonerism’ task). These tasks will be described more fully in the Method section below.

A few words are in order about areas of English phonology which do and do not overlap with English orthography. In this study, segmental and suprasegmental (i.e., stress) contrasts are being used as indexes of orthography-overlapping and non-orthography-overlapping phonology respectively. The advantages of using stress contrasts are two-fold. Fundamentally, they cannot be distinguished on the basis of English orthography (compare fore-stressed *steel warehouse* 'warehouse containing steel' and end-stressed *steel warehouse* 'warehouse made out of steel'; the pair require to be produced with the appropriate stress pattern in order to be correctly interpreted). Additionally, and more usefully, this is one of the few phenomena in English phonology which can be exploited to provide a near-equivalent to phonemic contrasts which do not involve segmental phonemes. Although stress can be conceptualised as attaching to units which are orthographically represented, in each of the suprasegmental tasks, the focus is on stress itself, not the segmental units it is associated with.

Predictions for the outcomes of these tasks vary according to the theoretical position adopted. Here we offer predictions from the perspective of the conventional Phonological Deficit Hypothesis (Snowling, 2000; Vellutino, et al., 2004). With respect to Question (1), this hypothesis assumes that the underlying cause of dyslexia is not an impairment of phonology that is specific to orthography, but rather one that is related to the general ability to use speech codes in representing words. By default, we assume that such a deficit is meant to apply to any type of phonological representation (e.g., phonemes, stress), although it is frequently illustrated using units no larger than phonemes (e.g., Snowling, 2000; Vellutino, et al., 2004). This hypothesis would therefore predict that the performance of the dyslexic group will be weaker than that of controls in both the segmental (orthography-linked) and the suprasegmental (non-orthography-linked) versions of each task.

A problem with the use of speech codes in representations should affect phonological performance regardless of the degree to which metalinguistic processes are involved. Thus for Question (2), the Phonological Deficit Hypothesis would predict that the dyslexic group will be impaired in the tasks with lesser metalinguistic demands as well as the tasks with greater metalinguistic demands.

Method

Participants

The dyslexic group consisted of twenty-one students at universities in Scotland, who had been given a formal diagnosis of dyslexia (7 males, 14 females). The mean age was 24;2 years (range 17;5-41;4). None reported a history of speech/articulation or hearing difficulties. Potential participants with additional diagnoses such as dyspraxia and ADHD were excluded. Fifteen provided information about the time of their diagnosis of dyslexia; 6 were diagnosed in primary school, 5 in secondary school, and 4 after leaving school. The group of individuals with dyslexia was matched with a group of controls for age and gender. The control group consisted of twenty-one students who had no history of speech/language/literacy impairment and had never been diagnosed as having dyslexia (7 males, 14 females). The mean age of the control group was 24;1 (range 17;6-42;5). All participants spoke English as their native language. Ethical approval was granted for this study.

Three background tasks were administered to both groups of participants.[1] For the Reading subtest of the Wide Range Achievement Test (WRAT-3) (Wilkinson 1993), the dyslexic group's mean standard score of 98 (range 77-116, SD 9.9) was significantly lower than the control group's mean standard score of 108 (range 92-118, SD 7.1), $t = 3.5$, $df = 18$, two-tailed $p = .002$. For the WRAT-3 Spelling subtask, the dyslexic group's mean standard score of 101 (range 73-114, SD 9.6) on the spelling task was significantly lower than the controls' mean standard score of 110 (range 103-119, SD 5.3), $t = 3.9$, $df = 18$, two-tailed $p = .001$. For the British Dyslexia Association checklist, the dyslexic group's mean number of 11.9 'yes' responses (range 7-19, SD 3.7) was significantly higher than the controls' mean of 4.7 (range 2-10, SD 2.1), $t = 8.8$, $df = 20$, two-tailed $p < .001$. The WRAT scores for the two groups are comparable to those which have been reported in other studies of students with dyslexia at university or about to enter university (e.g. Gallagher et al., 1996; Hatcher et al., 2002; Ramus, Rosen, et al., 2003). These results were taken to confirm the self-reports of dyslexia provided by the participants.

Materials

Four tasks were designed, varying in the extent to which they made demands on participants' metalinguistic analysis. Additionally, the use of both a segmental and a suprasegmental version for each task allowed experimental control over whether or not each task could be performed by making recourse to orthographic knowledge. The four tasks are listed below in order of increasing demands of metalinguistic knowledge.

Picture Matching Task. The stimuli for the *segmental* version of this task consisted of audio recordings of 36 monosyllabic CVC words, each of which belonged to a minimal pair that contrasted either word-initially (e.g., *bat*, *mat*) or word-finally (e.g., *back*, *bag*) (see Table 1 in the Appendix for a full list of items). Each word was matched with two pictures, corresponding to the two members of that minimal pair (e.g., the soundfile 'bat' was matched with pictures of a bat and a mat). These materials were based on the 'Minimal pair discrimination with pictures' subtask of the PALPA (Kay, Lesser, & Coltheart, 1992), used by permission.

The stimuli for the *suprasegmental* version of the Picture Matching task consisted of audio recordings of 21 stress-based minimal pairs such as *'toy factory* versus *toy 'factory* (pairs which rely on stress in order to distinguish a compound from a phrase), and *'hotdog* versus *hot 'dog* (pairs which rely on stress to distinguish an idiomatic lexical item from a phrase) (see Table 2 in the Appendix for a full list of the experimental items). Both types of pairs take either a compound interpretation or a phrasal interpretation depending on what stress pattern they are realised with (i.e., fore-stress or end-stress respectively). Each item was located in the syntactically neutral carrier frame, "This is what a ______ looks like." As with the segmental minimal pairs, each auditory item was matched with two pictures. For example, "This is what a toy factory looks like" was matched with a picture of a factory producing toys, and a picture of a miniature model factory for children to play with. There was also an equal number of filler items, which were not included in the analysis. The fillers consisted of equal numbers of compound nouns (such as *milkman*, matched with pictures of a milkman and a frogman) and phrases (such as *empty box*, matched with pictures of an empty box and an empty glass).

Unit Monitoring Task. The stimuli for the *segmental* version of this task consisted of audio recordings of 24 phoneme-based minimal pairs, half of which were pairs involving /s/ (e.g., *fussy-fuzzy*; *release-relief*) and half involving /t/ (e.g., *sonnet-sonic*; *limpet-limpid*) (see Table 3 in the Appendix for a full list of items). The /s/ and /t/ phonemes were arbitrarily chosen from the classes of fricatives and voiceless stops. All the items were bisyllabic and none of the contrasts were located word-initially. Note that in Scottish English, /t/ in these contexts can be realised either as a voiceless stop or a glottal stop (but not an alveolar flap, as in American English); in the realisations of all the words used in this task, /t/ was a voiceless stop.

The stimuli for the *suprasegmental* version consisted of audio recordings of 20 stress-based minimal pairs, none of which were the same as those used in the Picture Matching task (e.g., *'steel warehouse* vs. *steel 'warehouse*; *'blackbird* vs. *black 'bird*). See Table 4 in the Appendix for a full list of the experimental items. An equal number of near-minimal pairs were also presented as fillers, and were not included in the analysis (e.g., *'briefcase* vs. *brief 'chase*; *'toothpaste* vs *blue 'paste*).

Pig Latin Judgment Task. The stimuli for the *segmental* version consisted of audio recordings of 35 bisyllabic items drawn from Pennington et al. (1990) (see Table 5 in the Appendix for a full list of items). Twelve items began with biconsonantal clusters (e.g., *blanket*), 12 with triconsonantal clusters (e.g., *splatter*), and 11 with a singleton (e.g., *habit*). Half of the items (n = 18) were paired with the correct Pig Latin form, and half (n = 17) were paired with foils. The Pig Latin form of an item was created following the method used by Pennington et al (1990). The initial consonant was moved to the end of the word and made the onset of an extra syllable suffix whose nucleus was always /e/ (e.g., *blanket* /blaŋkət/ becomes /laŋkət-be/). Foil types were constructed following the four types used by Pennington et al. (1990), with six ‘omission’ foils (e.g., *blanket* becomes *lanket-ey*), six ‘addition’ foils (e.g., *blanket-bey*), three ‘cluster’ foils (e.g., *anket-bley*), and three ‘non-segmentation’ foils (e.g., *blanket-ey*).

The stimuli for the *suprasegmental* version consisted of audio recordings of 34 trisyllabic words, half with a Strong-Weak-Weak (SWW) stress pattern (e.g., *'ca.len.dar*) and half with a Weak-Strong-Weak (WSW) pattern (e.g. *dog'ma.tic*) (see Table 6 in the Appendix for a full list of items). Half the items were paired with the correct Pig Latin form, and half were paired with foils. The Pig Latin forms were created by moving the main stress of the item one syllable towards the end of the word, and adding an extra syllable /ta/ at the end (e.g., *'ca.len.dar* becomes *ca.'len.dar-ta*; *dog.'ma.tic* becomes *dog.ma.'tic-ta*). Note that only the location of the word’s main stress was shifted, not the order of the syllables or segments. Two foil types were constructed for each stress pattern, with equal numbers of foils where stress remains in the same place (instead of being moved towards the end), and equal numbers of foils where stress was moved to the wrong place (to the last syllable for SWW items, e.g., *'ca.len.dar-ta*, *ca.len.'dar-ta*, and to the first syllable for WSW items, e.g., *dog'ma.tic*, *'dog.ma.tic-ta*).

Spoonerism Judgment Task. The stimuli for the *segmental* version consisted of audio recordings of 22 pairs of bisyllabic words (see Table 7 in the Appendix for a full list of items). Half the pairs consisted of words beginning with singleton consonants, and half with biconsonantal clusters. Half the items were correctly spoonerised and half were matched with a foil. To create a spoonerism, the initial consonant of both words was exchanged (e.g., the pair *plastic* and *craggy* becomes *clastic* and *praggy*). Note that only the first consonant in the onset is affected in the spoonerism, not the whole onset. There were three types of foil, one where only one consonant was exchanged (e.g., *plastic*, *praggy*), one where the whole cluster was swapped (e.g., *crastic*, *plaggy*), and one where the whole syllable was swapped (e.g., *hamster* and *signal* becomes *hamnal* and *sigster*).

The stimuli for the *suprasegmental* version consisted of audio recordings of 23 pairs of trisyllabic words (see Table 8 in the Appendix for a full list of items). Each pair consisted of one word with a SWW stress pattern and one with a WSW pattern. Half the items were correctly spoonerised and half were given a foil. To create a spoonerism, the location of the main stress in the words was exchanged (e.g., the pair *ca.'the.dral* and *'bad.min.ton* becomes *'ca.the.dral* and *bad.'min.ton*). There were two types of foil: in both types, one of the items in the pair had its stress shifted appropriately, but in addition, in one foil type the stress remained in the same place on the other item (e.g. *'ca.the.dral*, *'bad.min.ton*), and in the other foil type, the stress moved to the end of the item (e.g. *'ca.the.dral*, *bad.min.'ton*).

Procedure

Participants were tested individually. They were seated in a sound-deadened booth facing a computer monitor with a keyboard. The auditory stimuli were presented through headphones and participants made their response using two specified keys on the keyboard. The same two keys were used in all tasks. One key corresponded to the correct answer in half of the trials in each task.

Tasks were presented in order of increasing metalinguistic demands. The segmental Picture Matching task was always presented first, followed by the Unit Monitoring task (the order of segmental and suprasegmental versions of these two tasks were counterbalanced). Following both versions of these two tasks, the two manipulation tasks were presented, counterbalancing both the order of the task (Pig Latin and Spoonerism) and the version (segmental and suprasegmental). It was intended that by staging the tasks in order of increasing metalinguistic demands, the amount of metalinguistic analysis which a participant might undertake in the Picture Matching task would be kept to a minimum.

Verbal instructions were provided by the experimenter to each individual participant, and the same instructions were also provided on-screen before the task began. Sample words were however avoided in the on-screen instructions as they would necessarily have been written.

Each task was presented using E-Prime (Psychology Software Tools, Pittsburgh, PA). Items were automatically randomised by E-Prime in each task. In each task, there was a pause of 1 second after the participant made the response before the next item was played. The four tasks together took approximately 45 minutes to complete.

Picture Matching Task. Participants were instructed to select the picture which matched the word or sentence which they heard. Pictures and sounds were presented simultaneously. Participants made their choice of picture based on two pictures presented side by side on the screen (see Figure 1).

<Insert Figure 1 around here>

Unit Monitoring Task. Participants were given pre-recorded auditory instructions as to what particular sound they were to listen for. In the segmental version, to monitor for /s/, the auditory instructions were: “Think about the first sound in the word *sing*. It’s the same as the first sound in the word *soft*. Now listen for this sound in the words which follow.” The instructions to monitor for /t/ used the examples *ten* and *time*. In the suprasegmental version, it was explicitly pointed out to participants that the difference between *hotdog* and *hot dog* was in the way that they were stressed – either the ′hotdog pattern, or the DA-da pattern, and the hot ′dog, or da-DA, pattern. The target was then identified to the participant both by label (e.g. ‘the da-DA pattern’) and a sample sound (e.g., *black 'bird*). On each trial participants heard two items – one containing the target sound (phoneme or stress pattern) and the other consisting of its minimally different counterpart. There was an interval of 500 ms between the two members of each pair. Participants were required to state whether the target sound occurred in the first presented item or the second (e.g., whether /s/ occurred in *fussy* or *fuzzy*, or whether end-stress occurred in *hotdog* or *hot dog*).

Pig Latin Judgment Task. For the Pig Latin task, participants heard the original word followed by a manipulation of the word (either the correct Pig Latin form of the word or a foil), with an interval of 500 ms between the word and its manipulation. Prior to hearing the test items, the method of “Pig Latinizing” the words was illustrated to participants and they were given two practice items (or three if requested) in order to familiarise themselves with the task. In the task itself, participants were instructed to state whether the manipulation they heard was correct or not, in terms of the manipulation procedure which they had practiced. After the stimulus item was played, participants were shown a screen containing the word “yes” presented on the left hand side of the screen and “no” on the right hand side.[2]

Spoonerism Judgment Task. For both versions of the Spoonerism task, participants heard the pair of original words followed by a manipulation of those words (either the correct Spoonerism forms or a foil). There was an interval of 500 ms between the items in each pair and before the manipulation was played. Prior to being presented with the test items, the method of “spoonerising” the words was illustrated to participants and they were given two practice items (or three if requested) in order to familiarise themselves with the task. As in the Pig Latin task, participants were instructed to state whether the manipulation they heard was correct or not, in terms of the description they had practiced.

Results and Discussion

Accuracy and response time data was collected for each task. Since the Picture Matching and Unit Monitoring are binary forced choice tasks, and the Pig Latin and Spoonerism tasks are ‘yes-no’ tasks, signal detection analysis was used to measure accuracy. Accuracy results are therefore reported in terms of *d′* (Macmillan & Creelman, 2005). Response times were measured from the stimulus offset for all tasks. Response times for incorrect responses were not included in the analysis.

We first address the question of the role of orthography. The performance of the two groups is compared on both the segmental versions of the tasks (where the units of interest overlap with units of orthography) and the suprasegmental versions of the tasks (which do not rely on orthography). We then address the question of the effect of metalinguistic demands. The performance of the two groups is compared in the four tasks, ranging from low to high metalinguistic demands.

To start with we compared both groups of participants on the two versions of all four tasks. A 4x2x2 mixed ANOVA was conducted, with accuracy as the dependent variable, Task and Domain (segmental vs. suprasegmental) as within-subjects independent variables, and Group as a between-subjects independent variable. There were main effects of Group ($F(1, 36) = 9.93$, $p < .01$), Task ($F(3, 108) = 9.69$, $p < .001$), and Domain ($F(1, 36) = 74.13$, $p < .001$). There was an interaction between Task and Group ($F(2.24, 80.61) = 7.47$, $p < .01$) and an interaction between Task and Domain ($F(2.77, 99.60) = 17.42$, $p < .001$). There was no interaction between Group and Domain ($F(1, 36) = .22$, $p = .64$), and no interaction between Group, Task, and Domain ($F(2.77, 99.60) = .66$, $p = .58$). Figure 2 shows accuracy in the two versions of each of the four tasks.

<Insert Figure 2 around here>

When response time was the dependent variable, there were main effects of Task ($F(3, 105) = 54.44$, $p < .001$) and Domain ($F(1, 35) = 112.27$, $p < .001$). The effect of Group was non-significant ($F(1, 35) = .07$, $p > .79$). There was an interaction between Task and Domain ($F(3, 105) = 16.59$, $p < .001$). Figure 3 shows response time in the two versions of each of the four tasks.

<Insert Figure 3 around here>

The results of these analyses show that the extent to which the groups differed depends on the task, and the extent to which there was a domain effect also depends on the task. We therefore compare the results for each of the four tasks in turn, examining performance in both the segmental (orthography-overlapping) version and the suprasegmental (non-orthography-overlapping) version.

Picture Matching task. A 2x2 mixed ANOVA was carried out with accuracy as the dependent variable, phonological Domain (segmental vs. suprasegmental) as a within-subjects independent variable, and Group as a between-subjects independent variable. There was no effect for Group ($F(1, 38) = 1.49$, $p = .230$). There was a significant main effect for Domain ($F(1, 38) = 150.49$, $p < .001$), with lower accuracy in the stress version than the phoneme version. There was no interaction ($F(1, 38) = 2.19$, $p = .147$).

When response time was the dependent variable, there was no effect of Group ($F(1, 34) = 0.94$, $p = .340$). There was a significant main effect for Domain, with longer response times in the stress version than the segmental version ($F(1, 34) = 49.47$, $p < .001$). There was no interaction between Group and Domain ($F(1, 34) = .462$, $p = .502$).

Unit Monitoring task. A 2x2 mixed ANOVA was carried out with accuracy as the dependent variable, phonological Domain as the within-subjects factor, and Group as the between-subjects factor. There was no effect for Group ($F(1, 38) = .43$, $p = .517$). There was a significant main effect for Domain, with lower accuracy in the stress version than the phoneme version ($F(1, 39) = 103.34$, $p < .001$). There was no interaction ($F(1, 39) = .001$, $p = .970$.

When response time was the dependent variable, there was no effect for Group ($F(1, 39) = .22$, $p = .640$). There was a significant main effect for Domain, with longer reaction times in the suprasegmental version than the segmental version ($F(1, 39) = 27.71$, $p < .001$). There was no interaction between Group and Domain ($F(1, 39) = 1.13$, $p = .294$).

Pig Latin task. A 2x2 mixed ANOVA was run, with accuracy as the dependent variable, phonological Domain as the within-subjects factor, and Group as the between-subjects factor. There was a significant main effect of Group, with the control group showing higher accuracy than the dyslexic group ($F(1, 39) = 6.94$, $p = .012$). There was a significant main effect of Domain, with lower accuracy in the suprasegmental version than the segmental version ($F(1, 39) = 61.27$, $p < .001$). There was no interaction ($F(1, 39) = .82$, $p = .372$).

When response time was the dependent variable, there was no effect of Group ($F(1, 39) = 2.68$, $p = .110$). There was a significant main effect of Domain, with longer response times for the suprasegmental version ($F(1, 39) = 18.72$, $p < .001$). There was no interaction between Group and Domain ($F(1, 39) = .91$, $p = .345$).

Spoonerism task. A 2x2 mixed ANOVA was carried out, with accuracy as the dependent variable, phonological Domain as the within-subjects factor, and Group as the between-subjects factor. There was a significant main effect of Group, with higher accuracy in the control group ($F(1, 39) = 15.63$, $p < .001$). There was no effect for Domain ($F(1, 39) = 2.83$, $p = .100$). There was no interaction ($F(1, 39) = .17$, $p = .682$).

When response time was the dependent variable, there was no effect for Group ($F(1, 39) = .52$, $p = .474$), or for Domain ($F(1, 39) = 0.18$, $p = .675$). There was no interaction between Group and Domain ($F(1, 39) < .001$, $p = .993$).

This consideration of the individual tasks allows us to address Question 1: How do the groups compare in tasks which do and do not exclude orthographic knowledge? In the Picture Matching and Unit Monitoring tasks, the suprasegmental versions were more difficult than the corresponding segmental versions, but no difference was found between the two groups. For these two tasks, therefore, there was no evidence for an impairment in areas of phonology which are not represented orthographically. On the other hand, in the Pig Latin and Spoonerism tasks, a difference was found between the groups, although it was only in the Pig Latin task that the suprasegmental version was more difficult than the segmental version (there was no effect of phonological domain in the Spoonerism task). In these two tasks, therefore, the dyslexic group was impaired relative to the control group both on the versions which do and do not allow recourse to orthographic knowledge.

These results also provide an answer to Question 2: How do the groups compare in tasks which vary in the metalinguistic demands they make? For both segmental and suprasegmental versions of the tasks, group differences were found only in the two tasks which had the highest metalinguistic demands (Pig Latin and Spoonerism tasks). In the two tasks with lower metalinguistic demands (the Picture Matching and Unit Monitoring tasks), the dyslexic group's performance was found to be no different from the control group's.

General Discussion

This study aimed to investigate implicit phonological representations as distinct from metalinguistic skills, while being sensitive to the need to distinguish phonological knowledge from familiarity with orthographic conventions.

Question 1. The results did not support the view that dyslexia involves a deficit in phonological representations which is independent of orthographic knowledge. If dyslexia involves a deficit independent of orthographic knowledge, it would be predicted that the dyslexic group would show weaker performance than the control group in both the segmental/orthographic and suprasegmental/non-orthographic versions of the tasks. However, no group differences were found in the Picture Matching or Unit Monitoring tasks, which required participants to use their knowledge of the spoken forms of words to identify the correct pictorial referent, and to identify contrastive units within spoken words, respectively.

The lack of evidence for a deficit in the segmental domains in the Picture Matching and Unit Monitoring tasks is perhaps surprising, since in addition to the well-established metalinguistic phoneme awareness deficits, there are reports of speech perception deficits in at least some individuals with dyslexia (e.g., Manis, et al., 1997). Had a deficit in the segmental versions of these tasks been found, it would of course still leave us with the puzzle over what exactly a deficit in segmental representations might mean, since given the closeness of the association between orthographic experience and the shaping of segmental phonological representations, there remains a pressing problem of how to distinguish between what is an orthographic problem and what is a segmental phonological problem.

On the other hand, we found no evidence of a deficit in suprasegmental phonology, suggesting that areas of phonology which have no orthographic counterpart may be intact in dyslexia. This is however at odds with a study of dyslexic children by Cheung et al. (2009), who specifically investigated the perception of Cantonese tone and aspiration contrasts, neither of which are represented orthographically. They showed that 10 year old Cantonese-speaking children with dyslexia had categorical perception deficits for both these contrasts, and they conclude that phonological processes are impaired in dyslexia regardless of whether or not the phonological units have orthographic counterparts. Since neither our tasks nor our participants are directly comparable with Cheung et al.'s, we would be keen to see how performance on our Picture Matching task would relate to performance on a categorical perception task involving the compound/phrasal stress distinction, especially in younger children with dyslexia.

Question 2. The prediction offered for the role of metalinguistic demands was that a deficit in phonological representations would manifest itself in a group difference in all four tasks. This was not borne out by the results. In the tasks which made heavy metalinguistic demands – requiring both metaphonological awareness and the ability to manipulate phonological elements – deficits were seen in the dyslexic group in the manipulation of both segmental and suprasegmental components of the presented words (Pig Latin and Spoonerism tasks). The standard interpretation of such phonological *manipulation* deficits is to say that they are due to impaired phonological *representations*, but our results do not support this. No deficit was found in the dyslexic group when the requirement of the task was simply to focus on the phonological form of a word and identify its phonological components (the Unit Monitoring task). Even more crucially for the question of implicit phonological representations, no deficit was found in the dyslexic group in the task which tested the implicit knowledge of suprasegmental contrasts (the suprasegmental version of the Picture Matching task). Since the suprasegmental Picture Matching task was specifically designed with a view to teasing apart the role played by orthographic knowledge from the role of knowledge specific to spoken language, we now have a basis for speaking to the question of phonological representations which are not confounded by contributions from orthographic knowledge, and it does not appear that the dyslexic group is impaired in this area of phonology.

Implications. These findings have particular implications for theories of dyslexia which place special emphasis on the role of phonological representations in this impairment. The results of the Pig Latin and Spoonerism tasks corroborate what has already been reported in the literature about the robustness and persistence of a deficit in dyslexia in the ability to manipulate phonological units even in adulthood (Birch & Chase, 2004; Bruck, 1992; Downey, et al., 2000; Gottardo, et al., 1997; Judge, et al., 2006; Pennington, et al., 1990, Snowling et al., 1997). The current results also extend these studies by showing a deficit in the manipulation of suprasegmental as well as segmental components of words. This provides more evidence for the well-established view that there is a phonology-*related* deficit in dyslexia, specifically in metalinguistic phonological manipulation. However, the current study does not allow this deficit in phonological manipulation to be traced back straightforwardly to a deficit in phonological *representations*: no difference was found between the dyslexic and the non-dyslexic group in the task which eliminated metaphonological and manipulation demands and drew only on putative phonological representations (the Picture Matching task). It would appear therefore that the deficits which are so widely found in dyslexia in tasks involving metaphonological manipulation must have an explanation somewhere other than in phonological representations. This is consistent with the conclusion reached by Ramus and Szenkovits (2008) that phonological representations in dyslexia may be intact, and also with the recent argument presented by Hazan et al. (2009) that there is little evidence to suggest that dyslexia is truly characterised by difficulties in speech perception, as the lack of robust evidence in favour of a speech perception deficit in dyslexia has always undermined the importance of the phonological deficit.

If phonological representations are indeed intact in dyslexia, one possibility for how to reconceptualise the role of phonology in dyslexia would be to look more closely at metaphonological skills, considered in their own right. It did not appear from the results of the Unit Monitoring task in the current study that the group of dyslexic participants had any impairment in low-demand metalinguistic skills. However, this outcome can be regarded as unexpected given phonological awareness deficits which are widely reported even in adulthood, based on phoneme and syllable counting tasks (Bruck, 1992; Pratt & Brady, 1988) and rhyme and alliteration judgments (Fawcett & Nicolson, 1995). In contrast to implicit phonological knowledge, phonological awareness has been specifically tested in the vast majority of studies which report a phonological deficit in dyslexia (see also the review by Vellutino et al. (2004)), which warrants treating the lack of a group difference in this task with caution unless further corroboration can be found.

Metaphonological skills, understood as distinct from implicit phonological representations, have been both associated with reading achievement and also predictive of future reading achievement (Goswami & Bryant, 1990; Snowling, 2000; Vellutino, et al., 2004; although see Scholes, 1998, and Castles & Coltheart, 2004, for alternative perspectives), and it has been shown that the relationship between speech perception and reading is best modelled as being mediated through phoneme awareness (McBride-Chang, 1996). For theories of developmental dyslexia which assign a crucial role to the phonological deficit, the smallest possible change which it seems advisable to make would be to explicitly implicate metalinguistic skills rather than phonological representations as impaired in dyslexia. Indeed it may well be the case that it is not ‘basic’ metalinguistic skills alone which are impaired. Certainly, the manipulation tasks (such as pig Latin and spoonerism tasks) which reliably elicit deficits in dyslexia in this and other studies demand facility in segmenting, manoeuvring, and blending arbitrarily specified units within words, and also rely fairly significantly on working memory, which has itself been observed to be impaired in dyslexia even in adults (see, for example, Fawcett & Nicolson, 1995; Pennington et al., 1991; Rack, 1997; Ramus, Rosen, et al., 2003).

There are aspects of the current study which require further investigation. As mentioned, one aspect would be the demand which metalinguistic manipulation tasks make on working memory: this should be addressed in future research. Another aspect concerns the population of individuals with dyslexia. There was some overlap between the dyslexia group and the control group in their scores on the WRAT subtasks, which suggests the individuals with dyslexia had a relatively mild impairment and perhaps sufficiently good compensatory strategies to enable them to pursue university courses (as suggested by Ramus, Rosen, et al. (2003)). Future work must also ascertain whether or not younger age groups, perhaps with more severe forms of dyslexia, will show the same behaviour as the university students tested here. Finally, it will be important to find cross-linguistic verification of the suprasegmental results. The suprasegmental phenomenon which we exploited in the Picture Matching and Unit Monitoring tasks is not strictly contrastive in English (although it can be regarded as quasi-phonemic, in Scobbie and Stuart-Smith’s (2006) terms), because the fore-stressed and end-stressed patterns are correlated with syntactic or semantic information, compoundhood and phrasality respectively. Since stress patterns in English are never truly contrastive, while phonemic contrasts are almost always encoded in orthography, it will be valuable to look at other languages to tease apart the orthography-contrastiveness confound more directly.

The present study has shown a deficit in manipulation skills in dyslexia in both segmental and suprasegmental aspects of words, while simultaneously showing no evidence of a deficit in implicit phonological representations or the ability to recognise phonological components within words. Subject to replication, this appears to provide support for the view that although there is substantial evidence for a phonology-related deficit in dyslexia, implicit non-orthographic phonological representations are not the best candidate for explaining this deficit.

Appendix: Materials

<Insert Table 1 here>

<Insert Table 2 here>

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<Insert Table 8 here>

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Notes

[1] One dyslexic participant did not participate in the Reading and Spelling tasks, one did not attempt the Spelling task due to time constraints, and in the case of a third, the Reading data was lost due to a technical difficulty.

[2] It is sometimes observed that school-children may spontaneously create or productively use "pig latin" as a language game, but participants were asked about this either when the instructions were given or in the debriefing at the end of the experiment, and none of the participants in either group was familiar with using pig latin as a language game.

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Table 1. Segmental Picture Matching task

(Modification of items used by Kay et al. (1992))

Word-initial contrast		Word-final contrast	
Auditory word	**Picture combination**	**Auditory word**	**Picture combination**
goat (practice)	coat, goat (practice)	hen (practice)	hen, hem (practice)
back	back, bat	bat	mat, bat
bag	bag, back	bead	deed, bead
bean	bean, beam	cap	cap, tap
bud	bud, bug	cut	gut, cut
coat	coat, code	deck	neck, deck
come	cub, come	dip	dip, tip
cub	cup, cub	fan	fan, van
fang	fan, fang	feed	seed, feed
fawn	fawn, fall	goal	goal, coal
head	hen, head	gown	down, gown
hiss	hiss, hit	line	line, nine
leaf	leave, leaf	lip	lip, nip
pig	pick, pig	pail	tail, pail
rice	rice, write	pill	bill, pill
robe	road, robe	pit	pit, kit
rope	robe, rope	pole	pole, bowl
run	rung, run	sail	tail, sail
tongue	tongue, tug	tack	sack, tack

Table 2. Suprasegmental Picture Matching task

Auditory word or phrase	Possible interpretations (with matching pictures): Compound interpretation	Possible interpretations (with matching pictures): Phrasal interpretation
hot+dog (Practice item)	A sausage snack	A dog which has the property of being hot
green+house (Practice item)	A glass enclosure for growing plants	A house which is green in colour
baby+photographer	Someone who takes photographs of babies	A baby taking photographs
blue+bottle	The name for a type of fly	A bottle which is blue in colour
bulls+eye	The target on a dartboard	The eye of a bull
cats+eyes	Reflective road markers	The eyes of a cat
German+teacher	Someone who teaches German	A teacher whose nationality is German
gold+fish	A type of tropical fish	An (ornamental) fish made of gold
gold+hammer	A tool for hammering gold	A hammer which is made of gold (or gold in colour)
head+hunter	Employment agent	The leader of a group of hunters
heavy+weight	Type of boxer	A weight which is heavy
high+chair	A raised chair for children to sit in at meals	A chair which has high legs
mini+driver	Someone who drives a	A driver who is miniature in

	Mini (type of car)	size
orange+tree	A tree which gives oranges as fruit	A tree which is orange in colour
origami+man	A man who practices origami	The figure of a man made through origami
paper+boat	A boat specially for transporting paper	A boat which is made of origami
pine+cone	A cone from a pine tree	A conical object made from pine wood
red+neck	A colloquial name for someone from the southern US states	Someone's neck which is red in colour
tight+rope	The wire which acrobats perform on	A rope pulled taut
toy+factory	A factory which produces toys	A pretend factory for children to play with
wet+suit	The rubber suit worn by divers and surfers	A suit which is wet
wood+chopper	A tool or a person which chops up wood	A chopping tool which is made of wood
wood+plane	A tool for planing down wood	A plane which is made of wood

Table 3. Segmental Unit Monitoring task

Location of target segment	Minimal pairs based on /t/	Minimal pairs based on /s/
medial	beater, beaker	fussy, fuzzy
	cattle, cackle	gristle, grizzle
	sleety, sleepy	muscle, muffle
	water, walker	useful, youthful
final	await, awake	bypass, bypath
	civet, civic	malice, mallet
	limpet, limpid	penance, pennons
	sonnet, sonic	release, relief
cluster	buster, busker	listed, lifted
	extend, expend	musty, mufti
	musty, musky	slipper, flipper
	streaming, screaming	unslung, unflung

Table 4. Suprasegmental Unit Monitoring task

Items
(practice) cylinder+connector
(practice) light+house
black+belt
black+bird
cardboard+shop
child+murderer
female+assassin
glass+case
gold+digger
green+belt
lamb+chops
Latin+lover
metal+separator
navy+flag
patient+queue
plastic+knife
plywood+warehouse
red+coat
steel+cable
steel+warehouse
white+house
white+wash

Table 5. Segmental Pig Latin task (subset of items used by Pennington et al. (1990))

Modification type	**Singleton onset**	**Biconsonantal onset**	**Triconsonantal onset**
Correctly Pig Latinised	habit (abit-hey)	braver (raver-bey)	screamer (creamer-sey)
	lady (ady-hey)	closet (loset-kay)	splatter (platter-sey)
	leather (eather-ley)	dragon (ragon-dey)	splendid (plendid-sey)
	rabbit (abbit-rey)	dresser (resser-dey)	splinter (plinter-sey)
	sudden (udden-sey)	flatten (latten-fey)	stranger (tranger-sey)
	weather (eather-wey)	platter (latter-pey)	stronger (tronger-sey)
Foil	feather (O)	blanket (O)	scraper (C)
	funny (A)	brother (O)	splitting (N)
	happen (A)	cleaner (A)	strainer (N)
	kitten (O)	driver (O)	strangle (N)
	mitten (O)	drummer (A)	streamer (C)
		flatter (A)	struggle (C)

Key to foil types (following Pennington et al (1990)). A: 'addition' foils, such as *blanket-bey*; O: 'omission' foils, such as *lanket-ey*; N: 'non-segmentation' foils, such as *blanket-ey*; C: 'cluster' foils, such as *anket-bley*

Table 6. Suprasegmental Pig Latin task

Modification	Items with SWW pattern	Items with WSW pattern
Correctly Pig Latinised	ˈbroccoli (broˈccoli-ta)	caˈthedral (catheˈdral-ta)
	ˈcalendar (caˈlendar-ta)	diˈmension (dimenˈsion-ta)
	ˈfactory (facˈtory-ta)	flaˈmingo (flaminˈgo-ta)
	ˈfurniture (furˈniture-ta)	conˈsumer (consuˈmer-ta)
	ˈgraduate (graˈduate-ta)	harˈpooner (harpooˈner-ta)
	ˈhexagon (/hekˈsagon-ta/)	meˈchanic (mechaˈnic-ta)
	ˈmagistrate (maˈgistrate-ta)	progˈnosis (prognoˈsis-ta)
	ˈregular (/regˈjular-ta/)	reˈvision (reviˈsion-ta)
	ˈsurgery (surˈgery-ta)	
Foil	daffodil (E)	curator (B)
	functional (E)	memento (B)
	membership (E)	robotic (B)
	wilderness (E)	safari (B)
	duplicate (S)	dogmatic (S)
	fisherman (S)	forensic (S)
	lunacy (S)	procedure (S)
	stamina (S)	proposal (S)
	victory (S)	

Key to foil types. S: stress remains in the same place, eg *'ca.len.dar-ta*; E: (for SWW items) stress moves two places towards the end rather than one place, eg *ca.len.'dar-ta*; B: (for WSW items) stress moves backwards rather than forwards in the word, eg *'dog.ma.tic-ta*

Table 7. Segmental Spoonerism task

Modification type	Singleton onset	Biconsonantal onset
Correctly Spoonerised	beckon, sandal (seckon, bandal)	clinic, prison (plinic, crison)
	fashion, noble (nashion, foble)	klaxon, brandy (blaxon, krandy)
	feather, serpent (seather, ferpent)	planter, grovel (glater, provel)
	lantern, kitten (kantern, litten)	plastic, craggy (clastic, praggy)
	puffin, legend (luffin, pegend)	
	saddle, baby (baddle, saby)	
	secret, ribbon (recret, sibbon)	
Foil	parsnip, visit (Con1)	glutton, proxy (Clus)
	random, tulip (Con1)	twenty, gravy (Clus)
	verdict, double (Con2)	clover, spirit (Syll)
	weapon, tinder (Con1)	tractor, scalpel (Syll)
	cabbage, motor (Syll)	trumpet, blazer (Syll)
	hamster, signal (Syll)	

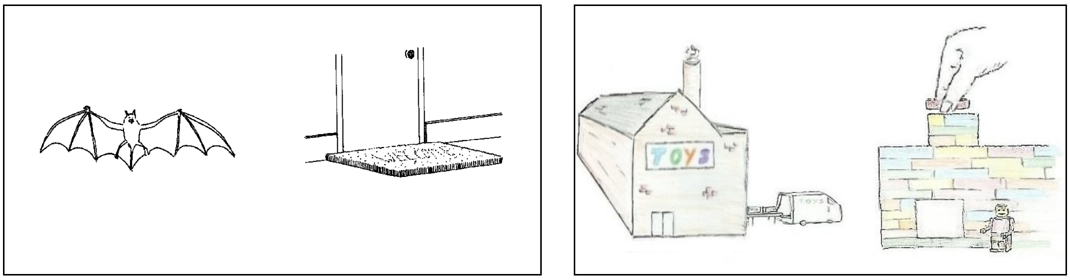
Key to foil types. Con1 and Con2: (for the items with singleton onsets) only the initial consonant of the first or second word respectively was replaced, eg *plastic*, *craggy* becomes *plastic*, *praggy*; Clus: (for the items with biconsonantal onsets) the whole cluster of each word was exchanged, eg *crastic*, *plaggy*; Syll: the whole syllable was exchanged, eg *ham.ster*, *sig.nal* becomes *ham.nal*, *sig.ster*

Table 8. Suprasegmental Spoonerism task

Modification	SWW-WSW pairs	WSW-SWWpairs
Correctly Spoonerised	ˈcrocodile, disˈclaimer	caˈthedral, ˈbadminton
	(croˈcodile, ˈdisclaimer)	(ˈcathedral, badˈminton)
	ˈfictional, preˈtender	draˈmatic, ˈplasticine
	(ficˈtional, ˈpretender)	(ˈdramatic, plasˈticine)
	ˈlegacy, sarˈcastic	elecˈtric, ˈsceptical
	(leˈgacy, ˈsarcastic)	(ˈelectric, scepˈtical)
	ˈnitrogen, coˈnundrum	equipment /iˈkwɪpmənt/, ˈpedantry
	(niˈtrogen, ˈconundrum)	(ˈequipment, peˈdantry)
	ˈpractical, tranˈsistor	fiˈasco, ˈtricycle
	(pracˈtical, ˈtransistor)	(ˈfiasco, triˈcycle)
	ˈtelescope, volˈcano	fraˈternal, ˈresident
	(teˈlescope, ˈvolcano)	(ˈfraternal, reˈsident)
Foil	cardigan, November (S2)	defender, magnitude (E1)
	gallantry, persona (S2)	explosive, aerodrome (E1)
	harvester, spectator (S1)	flamboyant, stalagmite (E2)
	spatula, credentials (S1)	frivolous, harmonic (E1)
	tornado, cranberry (S1)	horizon, wilderness (E2)
		stimulant, potato (E2)

Key to foil types. S1 and S2: stress remained in the same place on the first or second of the items respectively, eg *ca'the.dral*, *'bad.min.ton* becomes *'ca.the.dral*, *'bad.min.ton*; E1 and E2: stress moved to the end of the first or the second of the items respectively, eg *ca.the.'dral*, *bad.'min.ton*

Figure 1. Sample visual materials for segmental (left) and suprasegmental (right) versions of the Picture Matching task. Minimal pairs shown are “bat” and “mat” (segmental) and “′toy factory” and “toy ′factory” (suprasegmental).



Note. The materials for the segmental version of the Picture Matching task were adapted from *PALPA: Psycholinguistic Assessments of Language Processing in Aphasia*, by J. Kay, R. Lesser, & M. Coltheart. Copyright 1992 by the authors. Adapted with permission.

Figure 2. Mean accuracy (d') for segmental and suprasegmental versions of the four tasks (error bars indicate standard errors).

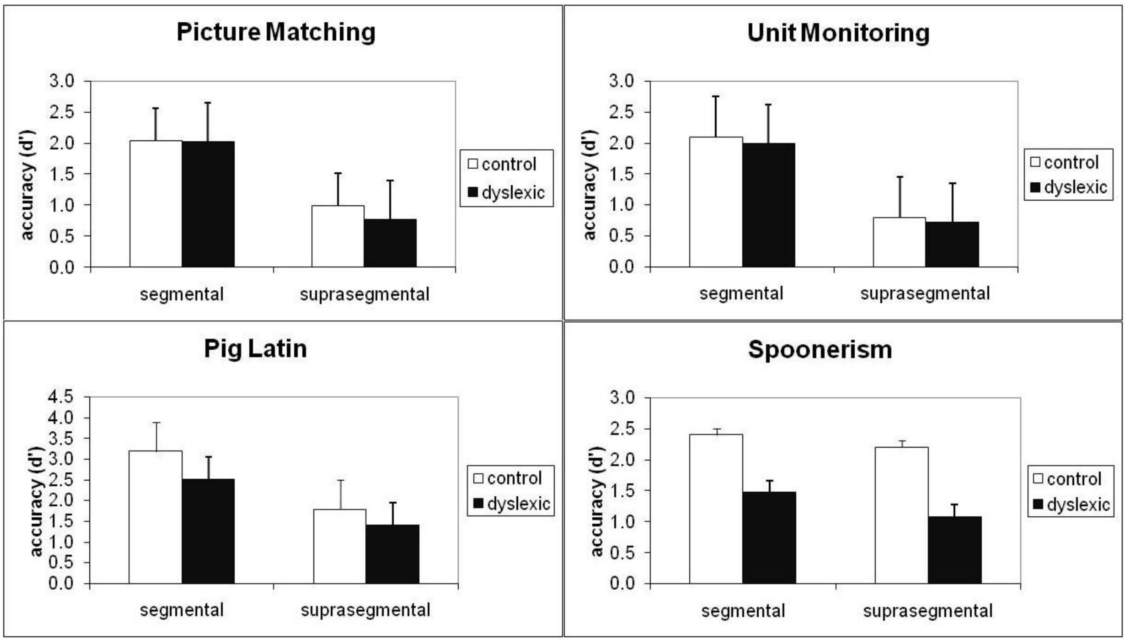


Figure 3. Mean response time (msec) for segmental and suprasegmental versions of the four tasks (error bars indicate standard errors).